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Full Research Article

Determination of Physical and Engineering Properties of Hydrogel Granules for Designing the Mechanical Hydrogel Applicator

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Abstract

Hydrogels are hard, off white amorphous polymers (hydrophilic materials) in physical appearance which have tendency to expand when they come in contact with water. Basically, the use of hydrogel granules is in the arid and semi-arid zone areas which receive less rainfall and having low soil moisture. PUSA Hydrogel can absorb water 350-450 times of its dry weight and gradually releases the same. The physical and engineering properties for three different sizes of hydrogel namely MS18, MS25 and MS36 were determined to design the metering mechanism of a mechanical hydrogel applicator for recommended hydrogel application rate i.e. 3 kg ha^{-1}. The hopper for hydrogel applicator machine was designed based on engineering properties like average angle of repose, coefficient of friction and bulk density of the different sizes of hydrogel granules. The distribution pattern for the recommended granule rate was affected by both size and shape of hydrogel granules. Free flow of granules in the hopper was influenced by angle of repose and coefficient of static friction. As mesh size (MS) of hydrogel granules increased, the roundness and spericity of hydrogel granules also increased. Angle of repose and coefficient of internal frictional on both mild steel and Aluminum surface increased when the mesh size of hydrogel granules was increased from MS18 to MS36.

1. Introduction

Hydrogel is a semi-synthetic cellulose derivative based polyacrylamide grafted and cross linked super absorbent material. This product was designed and developed specially to perform its intended job in the tropical and sub-tropical conditions (Sannino, 2008). Hydrogel application is done at the root zone depth for conserving water and releasing the same water slowly for saving irrigation water (Singh et al., 2007). As a practice, hydrogel application is done by different methods like mixing with soil and broadcasting manually for the application rate 3-4 kg ha^{-1}. But these methods are inaccurate, time consuming and much laborious. This problem can be overcome by applying granular hydrogel at proper root zone depth with a suitable applicator. A need based choice of application method can be made ensuring its placement just below the root or seed or in their immediate vicinity. Thus, to design the mechanical hydrogel applicator, the physical and engineering properties of the hydrogel must be known.

Pirard et al. (2005) determined physical properties of fertilizer by image analysis technique. A sample containing 300 g of each fertilizer was used for the experiment. A sample flows slowly and the particles were dispersed on a moving transparent belt placed above a light source. Valles et al. (2004) determined the degree of swelling and the mechanical properties of a family of hydrogels of acrylamide and itaconic acid or some of its monoitaconates. The degree of swelling and the elastic modulus can be tuned by varying the amount and type of co-monomer as well as the degree of cross-linking. The diversified physical properties of coir pith were evaluated and bulk density was found to be high when small particle sizes viz. 150 μ was considered and the former decreased when particle size increased to 2000 μ (Jeyaseeli, 2005).

Smaller size particles of coir arranged compactly arranged innumerable micro pores than the coarse particle which contains larger but limited amount of micro pores. As water retention in a medium depends upon primarily number and size of the pores and the specific surface area of the medium, it was observed to be higher in smaller sized particles.

Till today, very less information was available on the physical and engineering properties of hydrogel granules, hence; the main aim of this paper is to determine the physical and engineering properties like size, shape, 1000 granule weight, bulk density, angle of repose and coefficient of static friction for three different sample sizes of hydrogel i.e. MS18, MS25, MS36.These properties will be useful while designing the hydrogel feed hopper and metering mechanism of a mechanical hydrogel applicator.

2. Materials and Methods

The experiments for determining various physical and engineering properties of PUSA hydrogel were carried out in two laboratories (Division of Agricultural Engineering and Division of Agricultural Chemical, IARI New Delhi). The separation of different hydrogel sizes namely MS18 (0.85 mm), MS25 (0.60 mm), MS36 (0.42 mm) was done by mechanical sieve analysis from 1 kg sample which consisted of different sizes of hydrogel granules. The proportion of granules obtained on each sieve was measured in laboratory. Different hydrogel sizes can affect the metering systems in terms of particle distribution pattern over sticky belt due to varying physical and engineering properties of each hydrogel size. Physical and engineering properties for three sizes of hydrogel granules were measured using appropriate experimental methodology consisted of different materials and precise instruments (Table 1).

2.1. Size and shape of hydrogel granules

Size of the granules in terms of their length, breadth and thickness were measured using digital vernier caliper. The shape of the hydrogel granules was expressed in terms of roundness and sphericity. The per cent roundness was calculated as follows (Mohsenin, 1986).

$$Rp = \frac{Ap}{Ac} \times 100 \quad ....(1)$$

Where, Rp: Roundness (%), Ap: Projected area, (mm^2), A_c: Area of the smallest circumscribing circle (mm^2)

The projected area of the particle was measured by image analysis method. The area of the smallest circumscribing circle was calculated by taking the largest axial dimension

Table 1: Experimental set-up for measuring physical and engineering properties of PUSA hydrogel granules

Sl. No.	Properties	Test Variables	Parameters /properties to be assessed for
1.	Size (length, Breadth, Thickness, Geometric mean diameter)	H_1- MS 18 H_2- MS 25 H_3- MS 36 (3 Variables and 10 replications)	1. Groove length for a roller used in metering mechanism 2. Depth of a roller in metering mechanism 3. No. of hydrogel granules to be required on groove surface
2.	Shape (Roundness and spericity)	H_1- MS 18 H_2- MS 25 H_3- MS 36 (3 Variables and 10 replications)	1. Settlement and uniform free flow of hydrogel granules from the groove surface
3.	Bulk density and Particle density	H_1- MS 18 H_2- MS 25 H_3- MS 36 (3 Variables and 10 replications)	1. Design of a feed hopper for the hydrogel applicator
4.	Angle of repose	H_1- MS 18 H_2- MS 25 H_3- MS 36 (3 Variables and 10 replications)	1. Required slope for free flow of hydrogel granules from the hopper
5.	Coefficient of static friction	H_1- MS 18 H_2- MS 25 H_3- MS 36 (3 Variables and 10 replications)	1. To find out resistance for uniform and free flow for hydrogel granules
6.	1000 granule Mass	H_1- MS 18 H_2- MS 25 H_3- MS 36 (3 Variables and 10 replications)	1. No. of granules required for m^{-1} area

of the granule at natural rest position as the diameter of the circle. The procedure was repeated for randomly selected 10 particles from each size of hydrogel. The mean was taken as the characteristic value of roundness. The sphericity is a measure of shape character compared to a sphere of the same volume. Assuming that volume of the solid is equal to the volume of tri-axial ellipsoid with intercepts a, b, c and that the diameter of circumscribed sphere is longest intercept of the ellipsoid, the degree of sphericity was calculated as follows:

$$\text{Degree of Sphericity} = \frac{\sqrt[3]{a \times b \times c}}{a} \quad \text{....................(2)}$$

Where, DS: Degree of sphericity, a: Longest intercept (mm), b: Longest intercept normal to a (mm), c: Longest intercept normal to a and b (mm)

The procedure was repeated for randomly selected ten particles of each hydrogel size. The coefficient of variation and other statistical parameters were compared with each other for further analysis such as average percentage change in roundness and sphericity of hydrogel granules for three hydrogel sizes, t-value and standard error difference.

2.2. Bulk density

Bulk density of hydrogel granules was measured using a 100 ml measuring cylinder with inside dimensions of 3×20.5 cm. The cylinder was filled with hydrogel granules without compaction and then the mass was taken. The bulk density was calculated as follows:

$$BD = \frac{m}{v} \quad \text{....................(3)}$$

Where, BD is Bulk density (g cm^{-3}), V is Volume of cylinder (cm^3), m is Weight of granules in measuring cylinder (g).

The procedure was repeated for ten particles from each size and the average bulk density of the different size of hydrogel granules was calculated. This property was repeated for all the three sizes MS18, MS25 and MS36.

2.3. Angle of repose

The apparatus, used for measuring dynamic angle of repose, consisted of a funnel with an adjustable throat opening, mounted on a stand. The funnel was filled with hydrogel particle by keeping its adjustable throat closed (RNAM, 1991). The throat was fully opened to allow free flow of seed over and around the plate mounted in the funnel. At the end, a heap-cone of the granules was formed on the plate. The base diameter and height of cone was measured. The angle of repose was calculated with the following relationship:

$$Ø = \tan^{-1}[\frac{2h}{r}] \text{or } \tan Ø = H/R \quad \text{……………… (4)}$$

Where, Ø=Angle of repose (degree), h=Height of cone (cm) and d=Base diameter (cm)

2.4. Coefficient of static friction

The coefficient of static friction for two surfaces i.e. aluminum and mild steel were measured for the different PUSA hydrogel sizes by using inclined plane method. The material was kept on a horizontally placed surface and the slope was increased gradually. The angle (α) at impending slide was recorded. The coefficient of static friction was expressed by tanα. The procedure was repeated 10 times for each of PUSA hydrogel sizes to determine the mean correct angle of repose and coefficient of friction.

3. Results and Discussion

The various properties like size, shape, bulk density, angle of repose and coefficient of static friction for different size of granules were determined. The distribution of hydrogel in different sizes was also determined. The listed dimensions in Table 5 were used to determine the range of the design values of different components of the metering mechanism for example groove length, size of roller, hopper capacity and angle of hopper wall.

3.1. Size of the granule

The average length of the three hydrogel sizes MS18, MS25,

Table 2: Mean and coefficient of variation for different sizes of hydrogel

Parameters		Hydrogel Sizes (in mesh)			
		MS18	MS25	MS36	Mean
Length (mm)	Range	1.60-1.90	1.20-1.35	0.61-0.71	
	Mean	1.75	1.26	0.66	1.22
	CV%	5.48	4.25	3.82	
Breadth (mm)	Range	1.70-2.20	1.00-1.30	0.66-0.73	
	Mean	1.89	1.15	0.68	1.43
	CV%	7.25	7.92	3.21	
Thickness (mm)	Range	0.81-0.95	1-1.25	0.56-0.65	
	Mean	0.86	1.12	0.61	0.86
	CV%	4.75	6.98	3.21	
GMD (mm)	Range	1.34-1.52	1.10-1.24	0.61-0.69	
	Mean	1.41	1.17	0.65	1.08
	CV%	4.39	6.35	7.64	

Table 3: Shape of PUSA hydrogel granules at different mesh sizes

Shape parameter	Descriptive statistics	Hydrogel size in mesh			
		MS18	MS25	MS36	Mean
Sphericity %	Range	77.68-84.31	87.55-94.31	97.4-100	
	Mean	80.85	92.49	99	90.78
	CV%	2.83	2.23	1.05	
Roundness %	Range	38.64-52.35	83.33-98.37	92.4-99.8	
	Mean	49.69	88.46	96.9	78.35
	CV%	9.63	7.29	2.9	

and MS36 were 1.75 mm, 1.26 mm, and 0.66 mm, respectively. Breadth of three sizes granules in the same order of mesh size were 1.89 mm, 1.15 mm, and 0.68 mm, respectively when these properties were measured with the help of vernier caliper. Similarly, the mean thicknesses were 0.86 mm, 1.12 mm, and 0.61 mm, respectively. The mean dimensions of the PUSA hydrogel granules were used to determine the desired rate and distribution pattern of hydrogel on sticky belt (Table 2). Thus, as the mesh size of hydrogel changed from MS18 to MS36, the parameters like length and breadth of granule were decreased (Figure 1).

The significant difference was found between dimensions of length, breadth, thickness of different sizes of hydrogel when compared them at 5% level of significant. The geometric mean diameter was also decreased as the particle size of hydrogel decreased. So; the significant difference between each size of hydrogel was observed when tested at 5% level of significance.

3.2. *Shape of granules*

The measurement of roundness and sphericity of granules can be expressed as an important parameter of the shape of PUSA hydrogel granule. The sphericity and roundness of granule increased as the particle size of hydrogel decreased (Figure 2). The values of roundness were observed as 46.84%, 88.40% and 96.30% for granules MS18, MS25 and MS36 respectively (Table 4). No significant increment was observed in sphericity for three levels of PUSA hydrogel granules, but the variations were marginal. The sphericity of PUSA hydrogel granules were 80.85%, 92.49% and 99% for granules of sizes MS18, MS25 and MS35 respectively. Percent roundness was found to be highest for MS36 size of hydrogel particle (Table 3). The coefficients of variation for roundness and sphericity of granule were less than 10% in almost all the cases.

3.3. *Bulk density and particle density*

The bulk density and particle density of PUSA hydrogel granules varies inversely and directly with hydrogel size. It was found that there is a significant increase in bulk density as the

Table 4: Frictional properties of hydrogel particles

Frictional properties		Hydrogel sizes (in mesh)			
		MS18	MS25	MS36	Mean
Angle of repose (degree)	Range	37-41	40-44	41-46	
	Mean	39.6	42.18	43.9	41.83
	CV%	3.41	3.16	3.79	
Coefficient of friction	Range	0.75-0.95	0.84-0.86	0.78-0.97	
	Mean	0.83	0.85	0.88	0.853
	CV%	4.75	2.57	5.70	

Table 5: Average physical and engineering properties for three sizes of hydrogel

Parameters	Hydrogel size			
	MS18	MS25	MS36	Size*
Length, mm	1.75±0.20	1.26±0.11	0.66±0.07	1.22
Breadth, mm	1.89±0.33	1.15±0.23	0.68±0.06	1.24
Thickness, mm	0.86±0.11	1.12±0.15	0.61±0.06	0.86
GMD, %	1.41±0.15	1.16±0.10	0.64±0.06	1.07
Sphericity, %	80.85±4.35	92.49±2.64	99.0±2.0	90.78
Roundness, %	46.84±3.0	88.47±12.47	96.3±3.0	77.20
Bulk density, g cc^{-1}	0.31±0.03	0.56±0.05	0.79±0.7	0.55
Thousand granule weight, g	5.49±0.52	2.07±0.10	1.56±0.05	3.04
Angle of repose, degree	39.60±0.55	42.00±0.77	43.9±0.92	41.83
Coefficient of friction	0.83±0.55	0.85±0.16	0.88±0.21	0.85

*Average of three sizes

Table 6: Independent sample test between different hydrogel sizes (MS18, MS25 and MS36) with different hydrogel properties

Properties	Comparison*	t-test for equality of means			
		t-value	df	Sig**	SEd
Length	H_1-H_2	13.99	14.14	0.00	0.04
	H_2-H_3	32.21	12.88	0.00	0.02
	H_1-H_3	34.81	34.81	0.00	0.03
Thickness	H_1-H_2	9.61	13.50	0.00	0.03
	H_2-H_3	19.15	11.45	0.00	0.03
	H_1-H_3	15.07	16.37	0.00	0.02
Breadth	H_1-H_2	15.03	15.35	0.00	0.05
	H_2-H_3	15.08	10.10	0.00	0.02
	H_1-H_3	27.55	9.46	0.00	0.04
GMD	H_1-H_2	9.93	17.02	0.00	0.02
	H_2-H_3	29.33	13.02	0.00	0.17
	H_1-S_3	36.15	11.55	0.00	0.02
Sphericity	H_1-H_2	-11.96	17.82	0.00	0.97
	H_2-H_3	140.24	9	0.00	0.65
	H_1-H_3	110.79	9.01	0.00	0.72
Roundness	H_1-H_2	-20.88	15.84	0.00	2.05
	H_2-H_3	51.63	9	0.00	1.70
	H_1-H_3	38.88	9	0.00	1.15
Bulk density	H_1-H_2	-26.89	13.71	0.00	0.01
	H_2-H_3	-19.22	17.44	0.00	0.01
	H_1-H_3	-46.09	12.41	0.00	0.01
Porosity	H_1-H_2	1.04	14.94	0.31	1.03
	H_2-H_3	0.99	18	0.34	1.23
	H_1-H_3	2.24	15.05	0.40	1.02

*Comparison between group of hydrogel sizes; **2-tailed

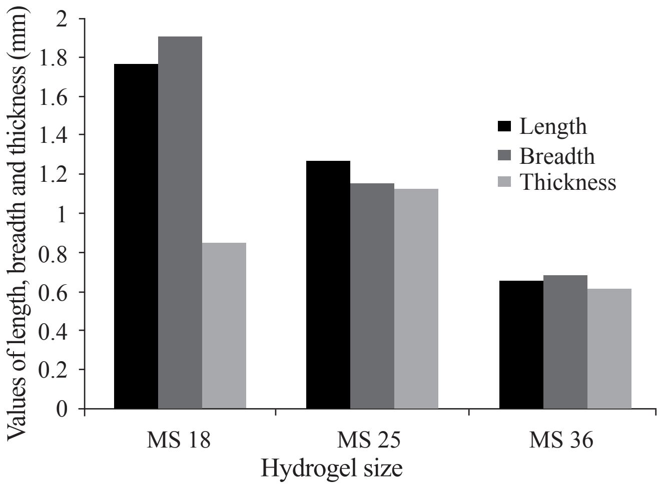

Figure 1: Length, Breadth and Thickness variations of three PUSA hydrogel sizes

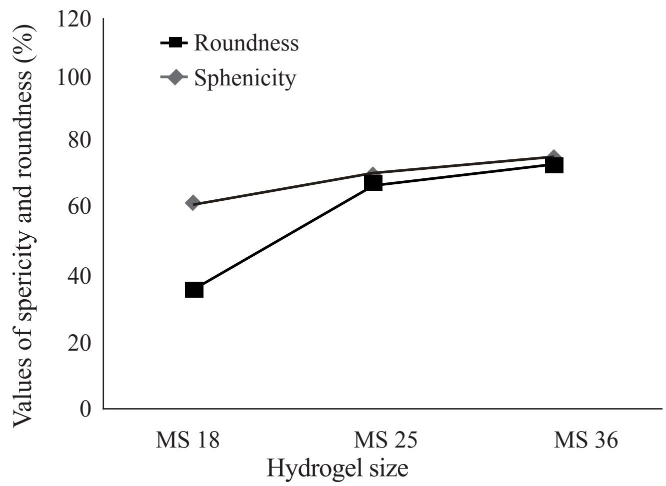

Figure 2: Sphericity and Roundness of three PUSA hydrogel sizes

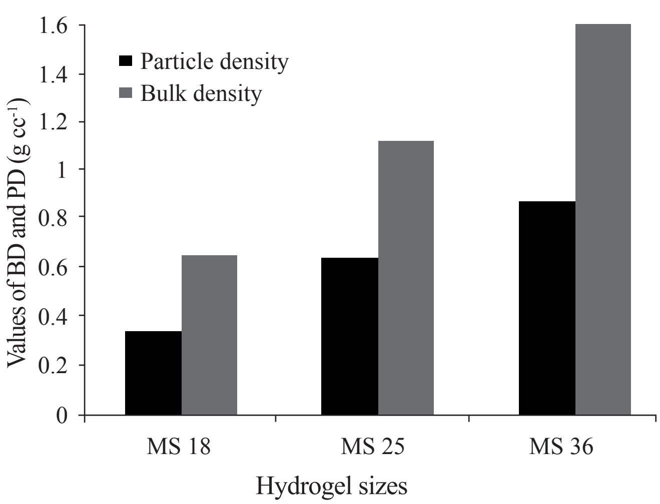

Figure 3: Variations in bulk density and particle density for three PUSA hydrogel sizes

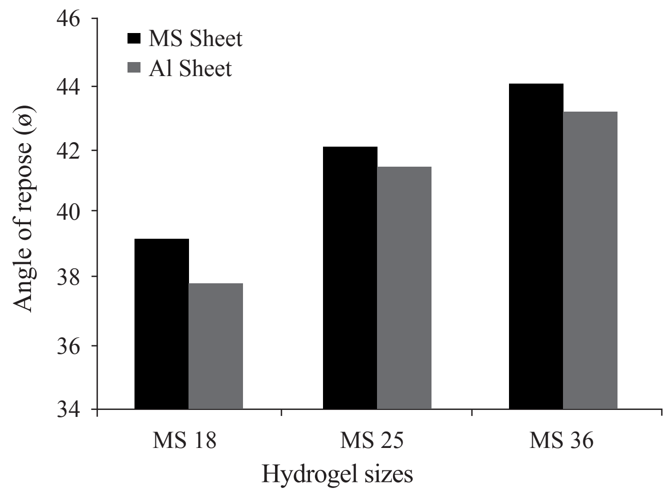

Figure 4: Variations in angle of repose for three hydrogel sizes on MS and Al sheet

mesh size of hydrogel increase from MS18 to MS36. The mean bulk density of MS18, MS25, and MS36 were 0.31, 0.56 and 0.79 g cc^{-1} respectively (Table 4). The average particle density and porosity of three types of PUSA hydrogel were 1.05 g cc^{-1} and 47.26% respectively (Figure 3). There was no significant difference found between two group sizes of hydrogel i.e. between MS18 and MS25 and MS36 when compared them at 5% level of significance (Table 6).

3.4. Thousand granule mass

The average granule mass for each size of PUSA hydrogel was determined for 1000 hydrogel particles. A significant difference in granular weight between three hydrogel sizes was observed. The granule mass for three sizes i.e. MS18, MS25, and MS36 were 5.49 g, 2.07 g, 0.79 g, respectively. So, it was observed that size of hydrogel varied directly with the granule weight. T-test showed a significant difference between thousand granular mass of each size of hydrogel.

3.5. Angle of repose and coefficient of friction

The angle of repose and coefficient of friction was determined for two surfaces mild steel (MS) and Aluminum sheet (Al). The average angle of repose on MS sheet for three sizes (MS18, MS25, MS36) were 39.6, 42.18, 43.9 degrees respectively (Figure 4). It was found that there were significant difference in the value of angle of repose and coefficient of friction of three sizes of hydrogel when compared each other at 5% level of significance. The average coefficient of friction on MS sheet and Al sheet for three sizes were 0.97 and 0.87 respectively. It was seen that this engineering property was also dependent upon the surface texture of the hydrogel granules and of that material to be used for manufacturing the hopper. Flow rate from the hopper can be affected due to less pore space available more because of compaction of small size particles which would result in hampering hydrogel application rate and forcing to keep more angle of repose for MS36 hydrogel granules. Thus, to design the hopper the average values of angle of repose and coefficient of friction were taken.

4. Conclusion

The average length, breadth and thickness for three hydrogel sizes MS18, MS25, MS36 for the design of a metering system were 1.22±0.12 mm, 1.24±0.20 mm, 0.86±0.10 mm. Average bulk density for three hydrogel sizes was 0.56±0.03 g cc^{-1}, which was useful in the design of hopper capacity. The increase in bulk density was resulted as the particle diameter decreases from mesh size MS18 to MS36. The angle of repose and coefficient of friction for various hydrogel sizes was varied with bulk density, roundness and surface texture of plate which can be played a vital role in the design of a hopper.

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